Wired for sound: A third wave emerges in integrated circuits

August 19 2019

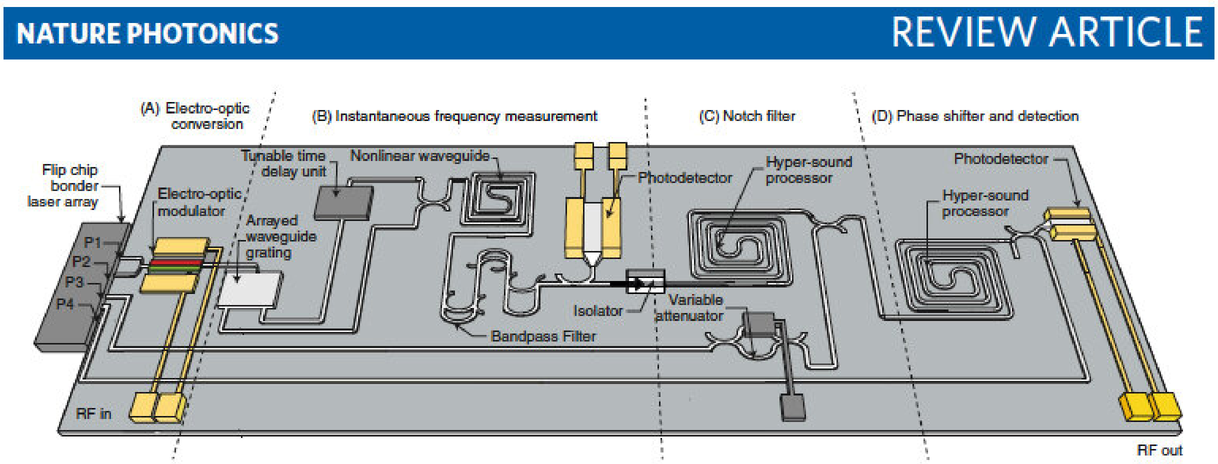

Fig. 5 | A chip-scale integrated microwave/RF processor for broadband communications. Incoming RF signals are (A) converted to photons and (B) spectrally analysed. The desired signal is (C) extracted and (D) processed before conversion back to RF. Functions (B), (C) and (D) all require strong on-chip optoacoustic interactions.

Conceptual illustration of integrated circuit incorporating stimulated Brillouin scattering devices. Credit: *Nature Photonics*

Optical fibres are our global nervous system, transporting terabytes of data across the planet in the blink of an eye.

As that information travels at the speed of light across the globe, the energy of the light waves bouncing around inside the silica and polymer fibres create tiny vibrations that lead to feedback packets of sound or acoustic waves, known as 'phonons'.

This feedback causes light to disperse, a phenomenon known as 'Brillouin scattering'.

For most of the electronics and communications industry, this scattering of light is a nuisance, reducing the power of the signal. But for an emerging group of scientists this feedback process is being adapted to develop a new generation of integrated circuits that promise to revolutionise our 5G and broadband networks, sensors, satellite communication, radar systems, defence systems and even radio astronomy.

"It's no exaggeration to say there is a research renaissance into this process under way," said Professor Ben Eggleton, Director of the University of Sydney Nano Institute and co-author of a review paper published today in *Nature Photonics*.

"The application of this interaction between light and sound on a chip offers the opportunity for a third-wave revolution in integrated circuits."

The microelectronics discoveries after World War II represented the first wave in integrated circuitry, which led to the ubiquity of electronic devices that rely on silicon chips, such as the mobile phone. The second wave came at the turn of this century with the development of optical electronics systems that have become the backbone of huge data centres around the world.

First electricity then light. And now the third wave is with sound waves.

Professor Eggleton is a world-leading researcher investigating how to apply this photon-phonon interaction to solve real-world problems. His research team based at the Sydney Nanoscience Hub and the School of Physics has produced more than 70 papers on the topic.

Working with other global leaders in the field, today he has published a review article in *Nature Photonics* outlining the history and potential of what scientists refer to as 'Brillouin integrated photonics'. His co-authors are Professor Christopher Poulton at the University of Technology Sydney; Professor Peter Rakich from Yale University; Professor Michael Steel at Macquarie University; and Professor Gaurav Bahl from the University of Illinois at Urbana-Champaign.

Professor Bahl said: "This paper outlines the rich physics that emerges from such a fundamental interaction as that between light and sound, which is found in all states of matter.

"Not only do we see immense technological applications, but also the wealth of pure scientific investigations that are made possible. Brillouin scattering of light helps us measure material properties, transform how light and sound move through materials, cool down small objects, measure space, time and inertia, and even transport optical information."

Professor Poulton said: "The big advance here is in the simultaneous control of light and sound waves on really small scales.

"This type of control is incredibly difficult, not least because the two types of waves have extremely different speeds. The enormous advances in fabrication and theory outlined in this paper demonstrate that this problem can be solved, and that powerful interactions between light and sound such as Brillouin scattering can now be harnessed on a single chip. This opens the door to a whole host of applications that connect optics and electronics."

Professor Steel said: "One of the fascinating aspects of integrated Brillouin technology is that it spans the range from fundamental discoveries in sound-light interactions at the quantum level to very practical devices, such as flexible filters in mobile communications."

The scattering of light caused by its interaction with acoustic phonons was predicted by French physicist Leon Brillouin in 1922.

Background information

In the 1960s and 1970s an interesting process was discovered where you could create an enhanced feedback loop between the photons (light) and phonons (sound). This is known as stimulated Brillouin scattering (SBS).

In this SBS process light and sound waves are 'coupled', a process enhanced by the fact that the wavelength of the light and sound are similar, although their speeds are many orders of magnitude apart: light travels 100,000 times faster than sound, which explains why you see lightning before you hear thunder.

But why would you want to increase the power of this Brillouin feedback effect?

"Managing information on a microchip can take up a lot of power and produce a lot of heat," Professor Eggleton said.

"As our reliance on optical data has increased, the process of interaction of light with microelectronics systems has become problematic. The SBS process offers us a completely new way to integrate optical information into a chip environment using sound waves as a buffer to slow down the data without the heat that electronic systems produce.

"Further, integrated circuits using SBS offer the opportunity to replace components in flight and navigation systems that can be 100- or a 1000-times heavier. That will not be a trivial achievement."

Reducing complexity

How to contain the process of light-sound interaction has been the sticking point, but as Professor Eggleton and colleagues point out in *Nature Photonics* today, the past decade has seen tremendous advances.

In 2017, researchers Dr. Birgit Stiller and Moritz Merklein from the Eggleton Group at the University of Sydney announced the world-first transfer of light to acoustic information on a chip. To emphasise the difference between the speeds of light and sound, this was described as 'storing lightning inside thunder'.

Dr. Amol Choudhary further developed this work in 2018, developing a chip-based information recovery technique that eliminated the need for bulky processing systems.

"It's all about reducing complexity of these systems so we can develop a general conceptual framework for a complete integrated system," Professor Eggleton said.

There is increasing interest from industry and government in the deployment of these systems.

Sydney Nano has recently signed a partnership with the Royal Australian Air Force to work with its Plan Jericho program to revolutionise RAAF's sensing capability. Companies such as Lockheed Martin and Harris Corporation are also working with the Eggleton Group.

The challenges ahead

There are barriers to overcome before this chip-scale integrated system can be deployed commercially, but the payoff in terms of size, weight and power (SWAP) will be worth the effort, Professor Eggleton said.

The first challenge is to develop an architecture that integrates microwave and radio frequency processors with optical-acoustic interactions. As the Eggleton Group results show, there have been great strides towards achieving this.

Another challenge comes with reducing 'noise' (or interference) in the system caused by unwanted light scattering that deteriorates the signal-to-noise ratio. One proposition is to have chips operating at cryogenic temperatures near absolute zero. While this would have significant practical implications, it could also bring quantum processes into play, delivering greater control of the photon-phonon interaction.

There is also a live investigation into the most appropriate materials upon which to build these integrated systems. Silicon has its obvious attractions given most microelectronics are built using this cheap, abundant material.

However, the silica used in the optic fibres when coupled with the silicon substrate means that information can leak out given the similarity of materials.

Finding materials that are elastic and inelastic enough to contain the light and sound waves while allowing them to interact is one suggested avenue. Some research groups use chalcogenide, a soft glass substrate with a high refractive index and low stiffness that can confine the optical and elastic waves.

Co-author of the review, Professor Steel from Macquarie University, said: "At this stage, all material systems have their strengths and weaknesses, and this is still an area of fruitful research.

Professor Eggleton said: "This new paradigm in signal processing using light waves and sound waves opens new opportunities for fundamental research and technological advances."

More information: Brillouin integrated photonics, *Nature Photonics* (2019). DOI: 10.1038/s41566-019-0498-z , nature.com/articles/s41566-019-0498-z

Provided by University of Sydney